Smallsat technology trends and their impact on the future of solar system exploration

Tony Freeman, JPL
Sept 2017
Jet Propulsion Laboratory, California Institute of Technology

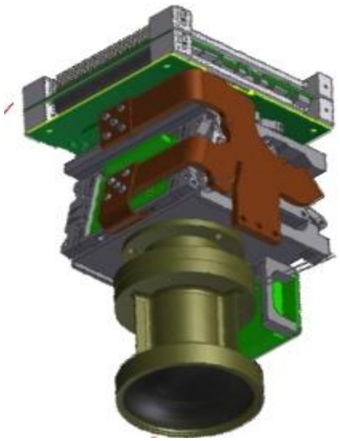
3rd COSPAR Symposium 2017, Jeju, S. Korea

Cubesats were 'toys' 18 years ago…


Disneyland, Anaheim, CA
https://www.planet.com/gallery/disneyland-parking-lot/

Science Instrument Examples (1U = 1 liter)

HARP Imaging Polarimeter(3U)

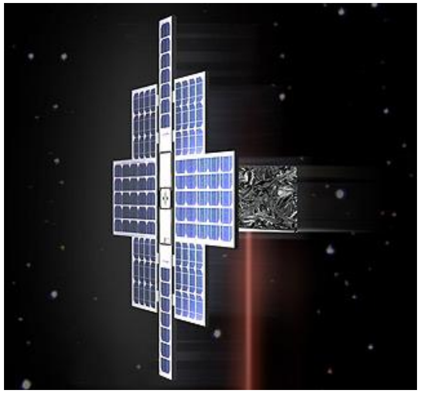


UMBC/SDL (2017)

RainCube radar (6U)

JPL (2017)

Lunar Flashlight (6U)
NIR laser



MSFC/JPL (2017)

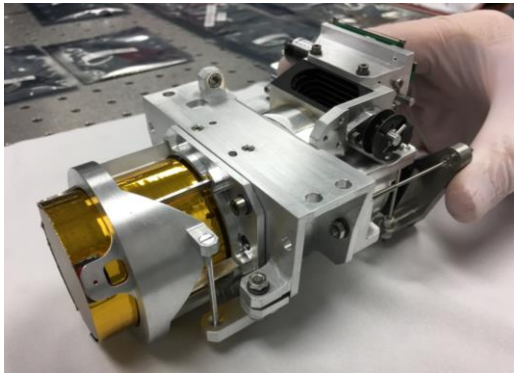
Mass Spectrometer (3U)

JPL (TBD)

LunarIceCube (6U)
IR spectrometer

GSFC (2018)

VSWIR-Dyson (2U)
spectrometer



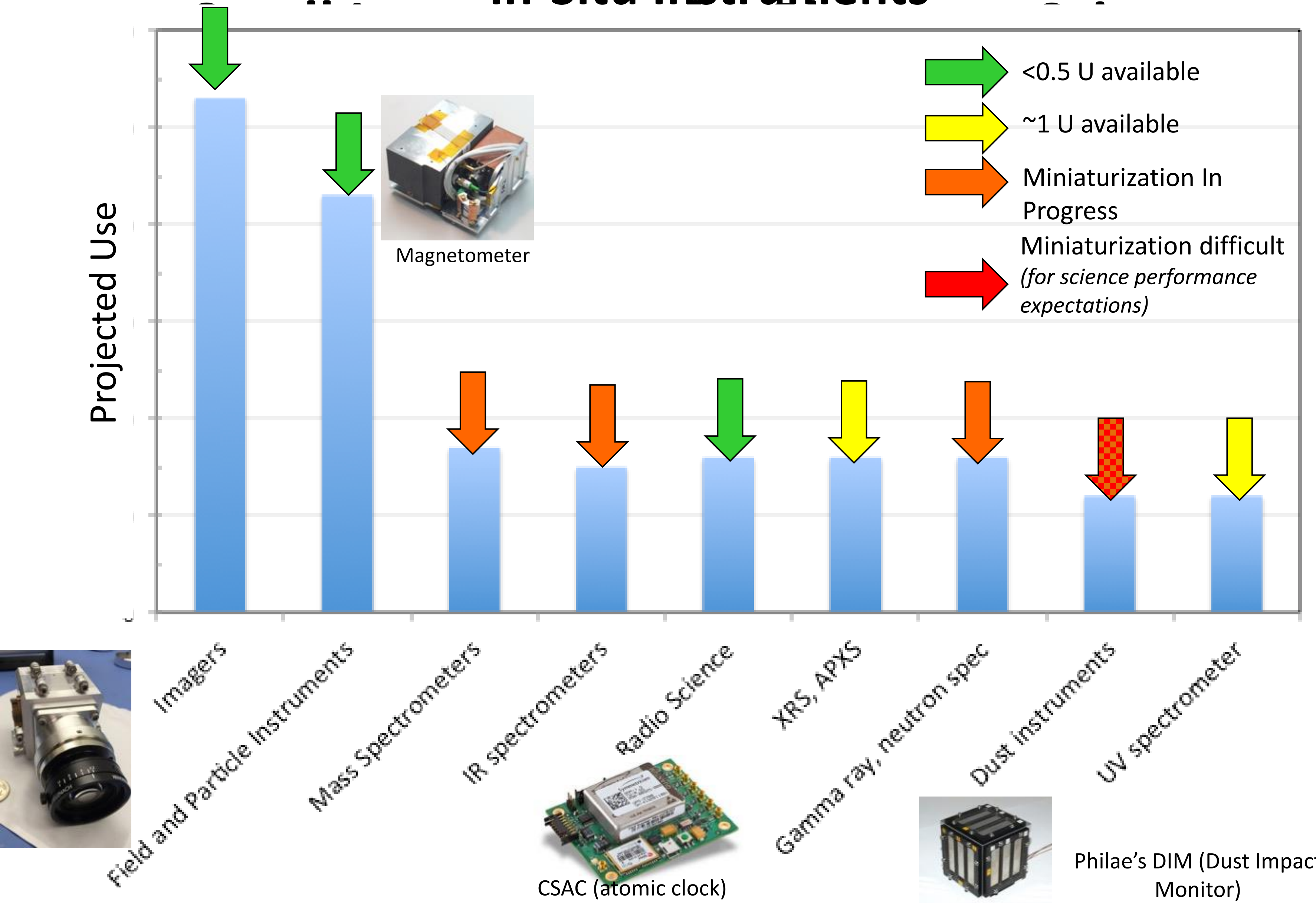
JPL (TBD)

Cubesat-sized Instruments – 2012 and 2017

Technology	Selva* and Krejci, 2012	Freeman 2017	Justification
Atmospheric Chemistry Instruments	Problematic	Feasible	PICASSO, IR sounders
Atmos Temp and Humidity Sounders	Feasible	Feasible	
Cloud Profile and rain radars	Infeasible	Feasible	JPL RainCube Demo
Earth Radiation Budget radiometers	Feasible	Feasible	SERB, RAVAN
Gravity Instruments	Feasible	Feasible	Need a demo mission
Hi-res Optical Imagers	Infeasible	Feasible	Planetlabs
Imaging microwave radars	Infeasible	Feasible	Ka-Band 12U design
Imaging multi-spectral radiometers (Vis/IR)	Problematic	Feasible	AstroDigital
Imaging multi-spectral radiometers (μWave)	Problematic	Feasible	TEMPEST,
Lidars	Infeasible	Feasible	DIAL laser occultation
Lightning Imagers	Feasible	Feasible	
Magnetic Fields	Feasible	Feasible	InSPIRE
Multiple direction/polarization radiometers	Problematic	Feasible	HARP Polarimeter
Ocean color instruments	Feasible	Feasible	SeaHawk
Precision orbit	Feasible	Feasible	CanX-4 and -5
Radar altimeters	Infeasible	Feasible	Bistatic LEO-GEO
Scatterometers	Infeasible	Feasible	GPS refl. (CyGNSS)

*Selva and Krejci, A survey and assessment of the capabilities of Cubesats for Earth observation, Acta Astronautica, 74, 50–68 (2012)

In-Situ Instruments



Slide courtesy J. Castillo-Rogez, JPL

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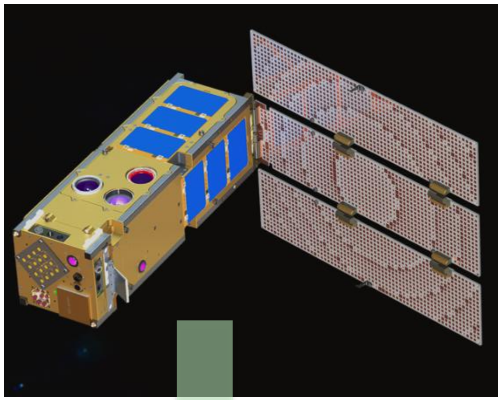
Telecom

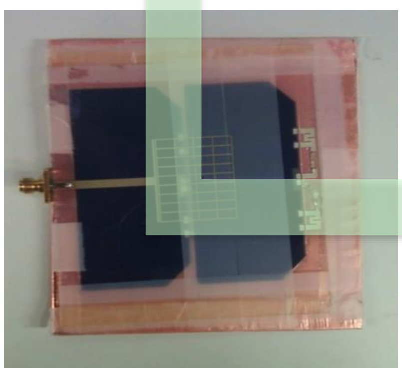
RF

ISARA
Reflectarray/Solar Array



JPL (2017)

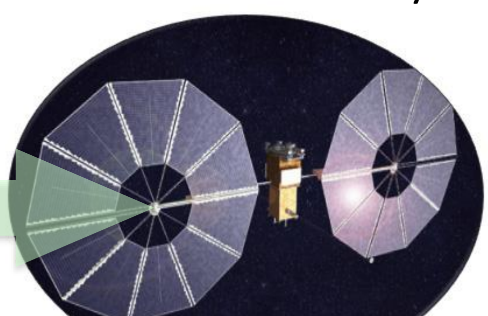
Optically Transparent/
RF Reflective Coatings



Utah State (TBD)

- RF Reflectarrays can scale to larger antennas
- Active and passive Optical Comm
- Optically transparent/RF reflective coatings printed on large solar arrays on deep space missions

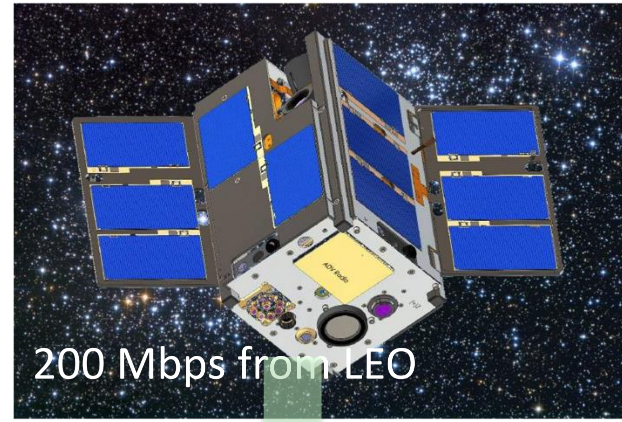
Dual-use Solar arrays



(TBD)

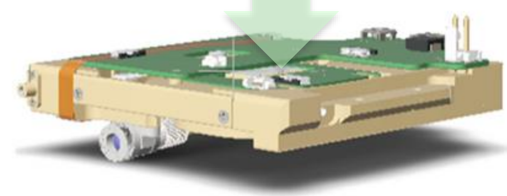
Optical

Cubesat Optical Comm Demo



Aerospace (2016/7)

Bridgesat Optical Comm Terminal



Bridgesat (TBD)

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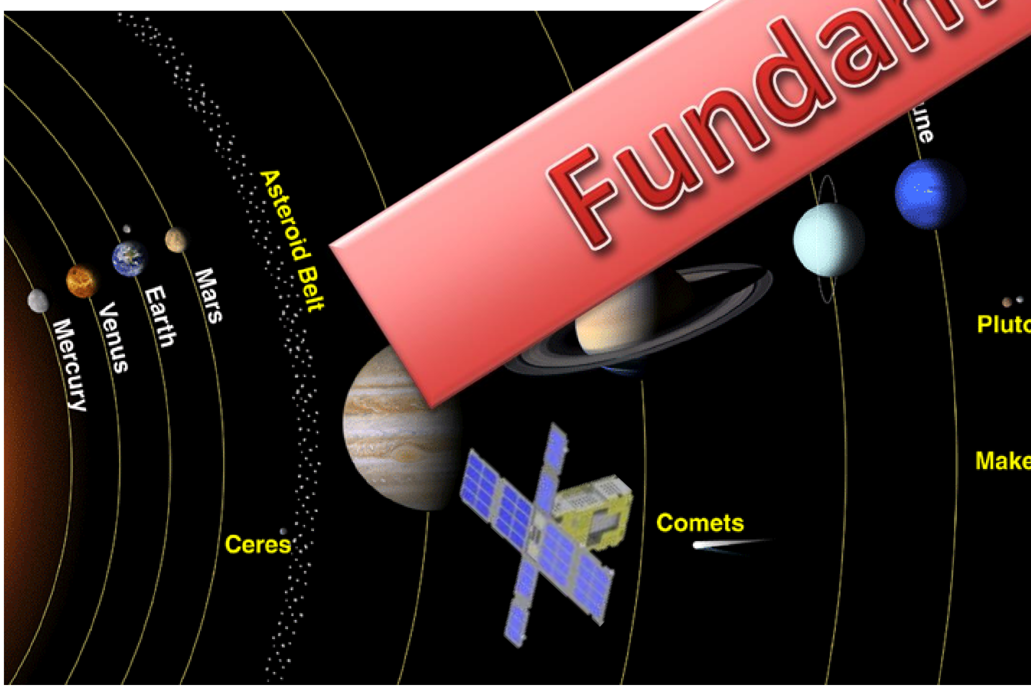
Power Systems

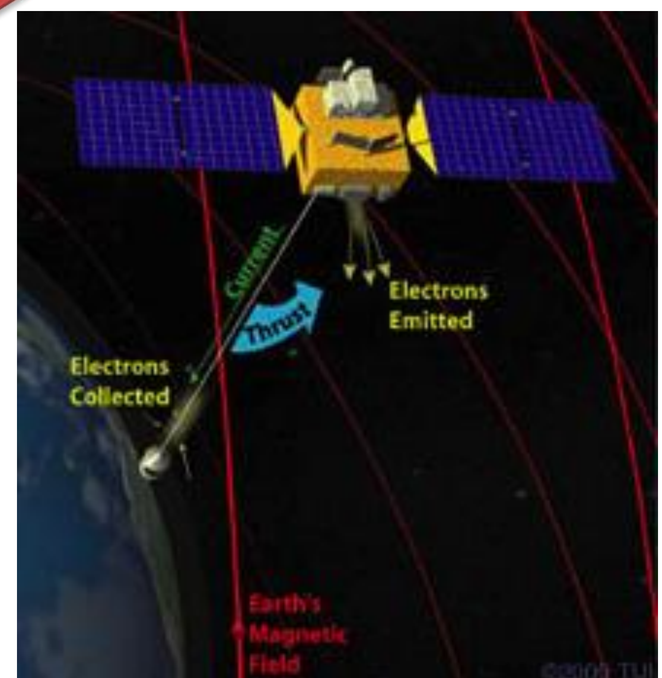
- Solar Array Plateau ~ 45% efficiency?
- Batteries that work over wide temperature ranges?
- Electromagnetic tethers – great if there's a ma
- Progress in nuclear dependent on NASA/ , Compact RTGs?

Fundamental

Solar power distance limit?

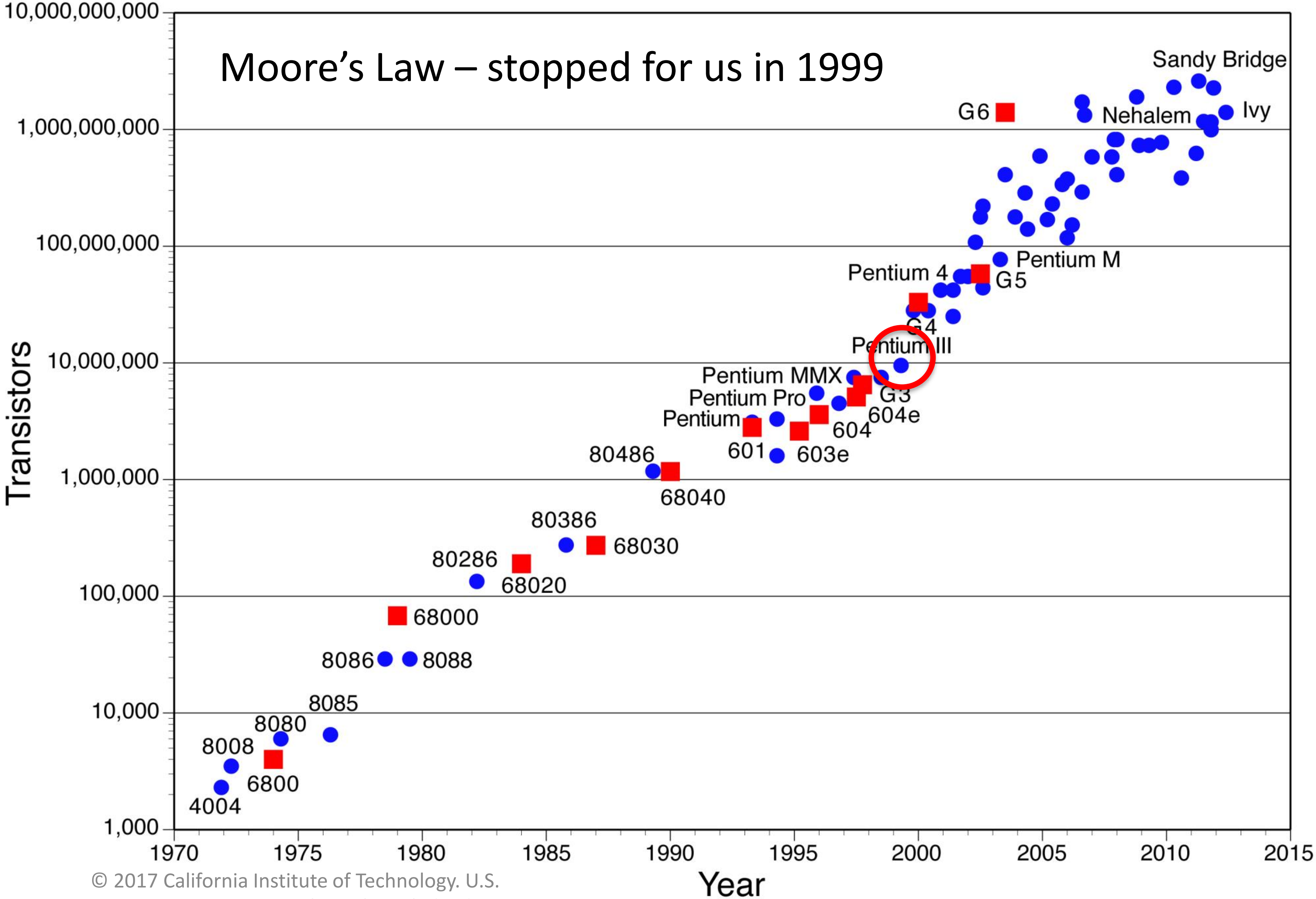


Electromagnetic Tethers



Tethers Unlimited (TBD)

Spacecraft S/W Functions



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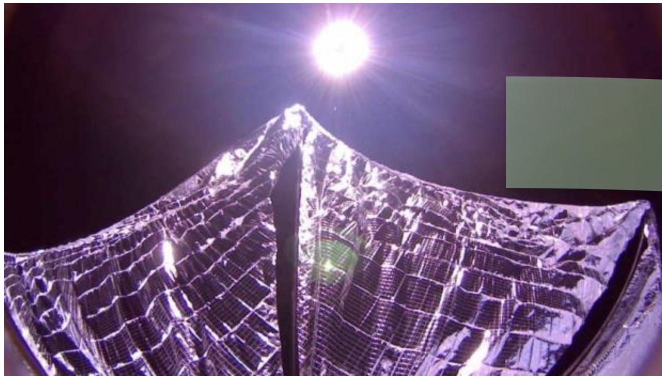
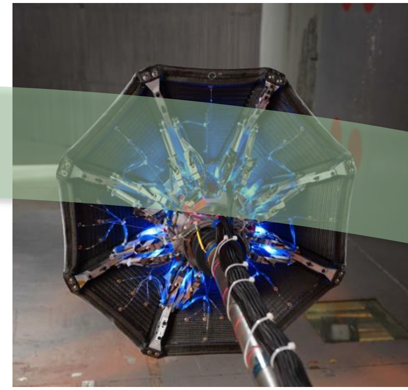
Propulsion

Solar Sail (first design in 1976)



Planetary Society (2015)

Deployable Aeroshell

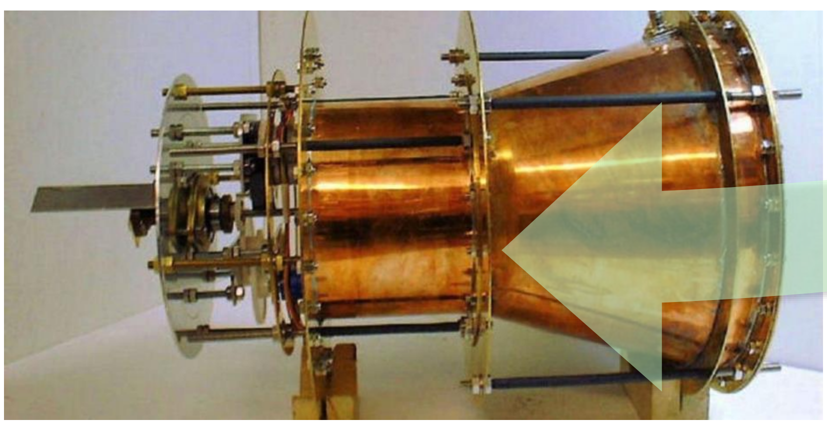


NASA Ames (2017)

MicroSpray
Electric propulsion

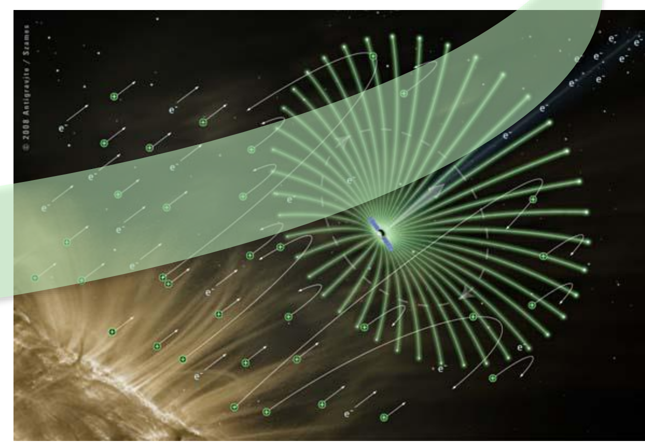
Busek (2019)

NASA EM Drive



NASA JSC (???)

eSail demo



Aaalto U. Finland (2017)

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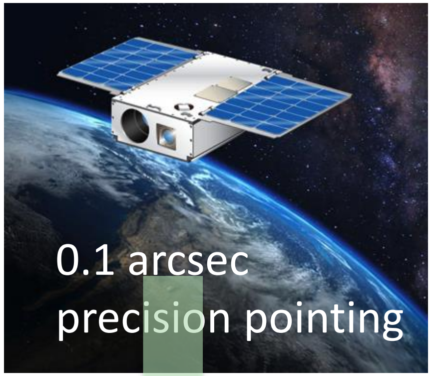
Attitude Determination and Control

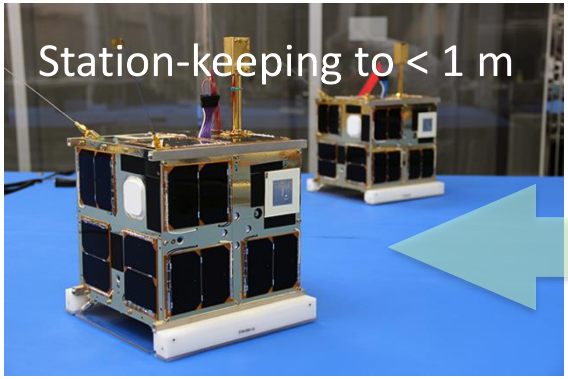
- Fraction of an arcsec pointing
- Navigation using Pulsars
- Precision Formation Flying

Asteria
Exoplanet Hunter



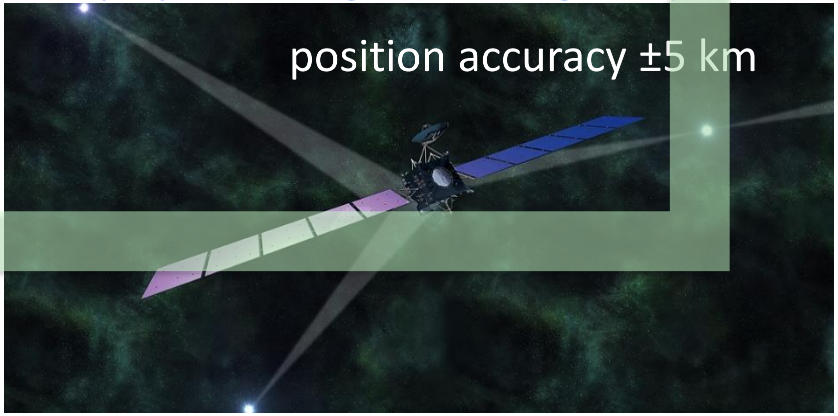
JPL/MIT (2018)

CanX-4 and -5
Precision Formation Flying



UTIAS SFL (2014)

XPNav-1
Deep Space navigation using X-ray Pulsars



China (2016)

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Cubesat Assembly
(in less than one workday)

Video clip courtesy Tyvak Corporation

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Advanced Manufacturing

- 3-D printed valves on Falcon-9
- 3-D printing of S/C components
- Multi-function Structures
- Robot-assisted Integration and Test
- S/C build cycles < 1 week

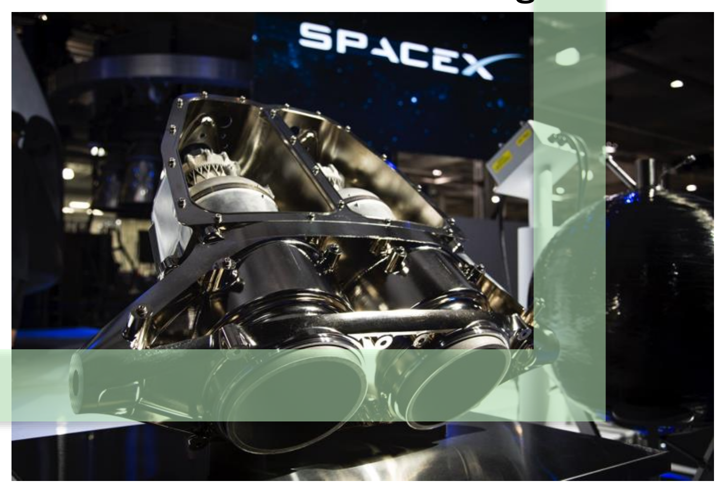
3D Printed Spacecraft

Planetary Resources (2014)

Robot-assisted assembly
[15 Smallsat S/C per week]

OneWeb (2018)

3-D Printed Rocket Engine



Space-X (2014)

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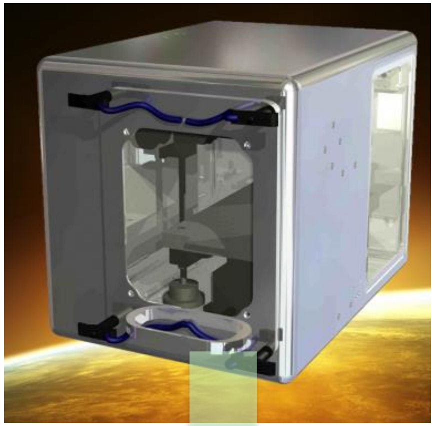
Additive Manufacturing

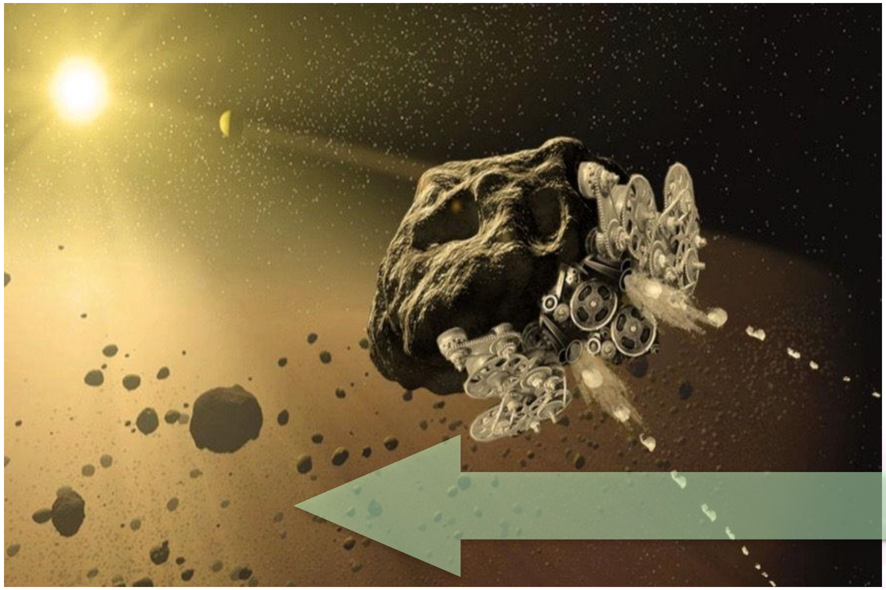
- 3-D printer as a flight payload
- Print Hardware Upgrades
- Use In situ resources
- Large-scale Structures in Space

First 3-D Printer in Space



Made In Space on ISS (2014)

Making a Spacecraft out of an Asteroid



Made In Space (TBD)

Object printed from asteroid metals

Planetary Resources (2016)

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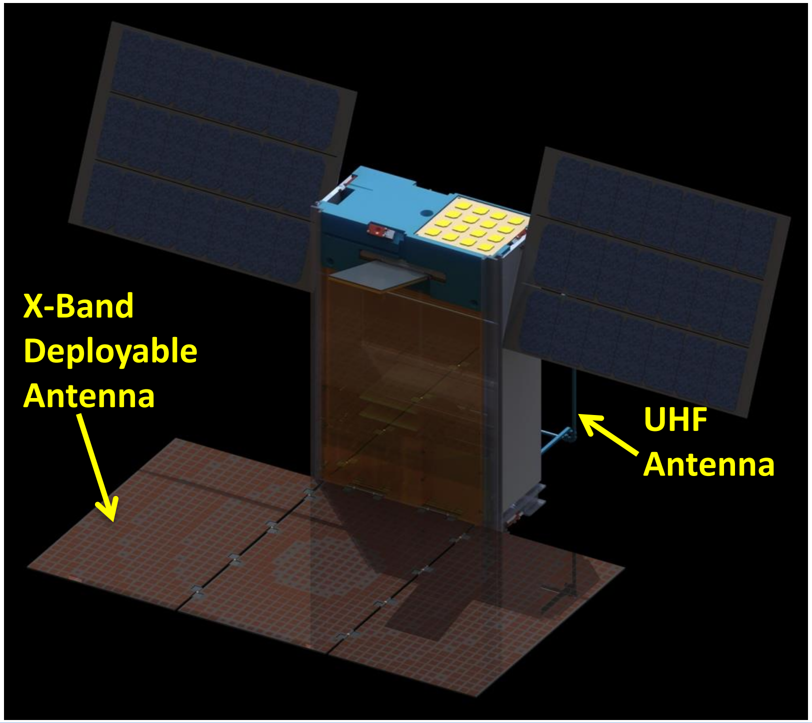
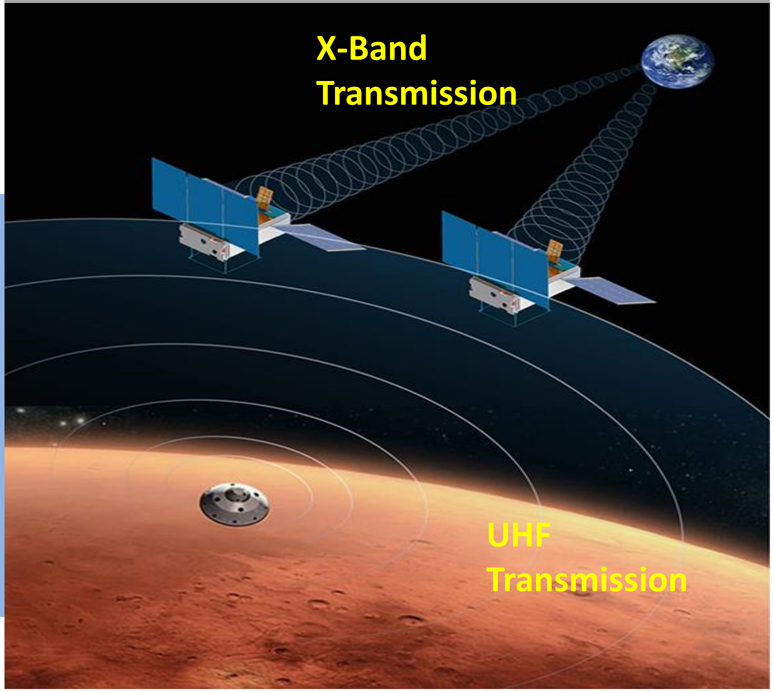
Mars Cube One



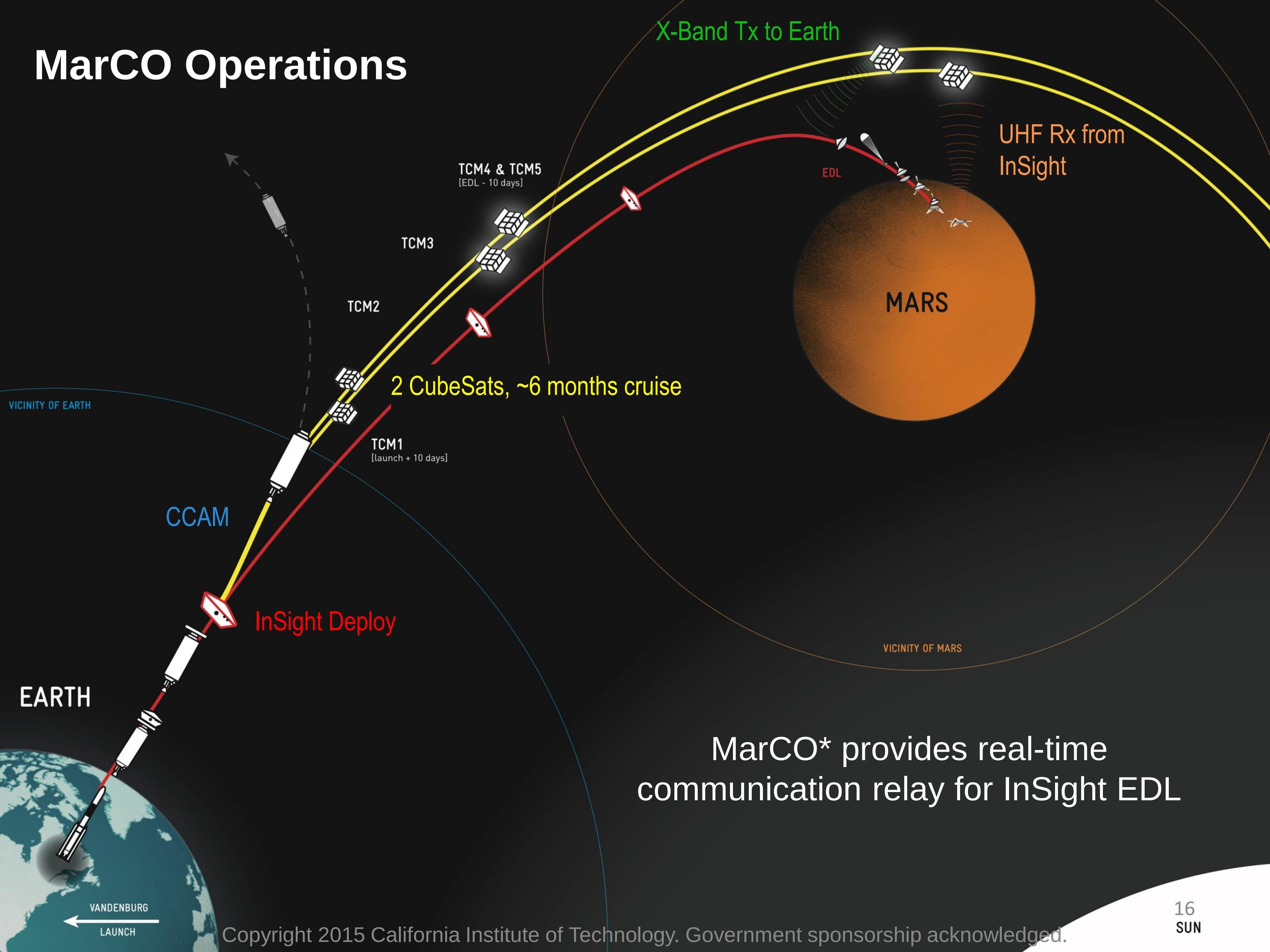
A Technology Demonstration of communications relay system for Mars missions' critical events such as the 2016 InSight entry, descent, & landing.

Interplanetary Travel
Flyby Mars



- **Two redundant 6U CubeSat spacecraft**
- **Launch: Mar. 2016; Arrival: Sep. 2016**
- **Real-time relay of InSight EDL data**
  - **UHF link: InSight lander to MarCO**
  - **X-band link: MarCO to Earth**

MarCO Operations



MarCO* provides real-time communication relay for InSight EDL

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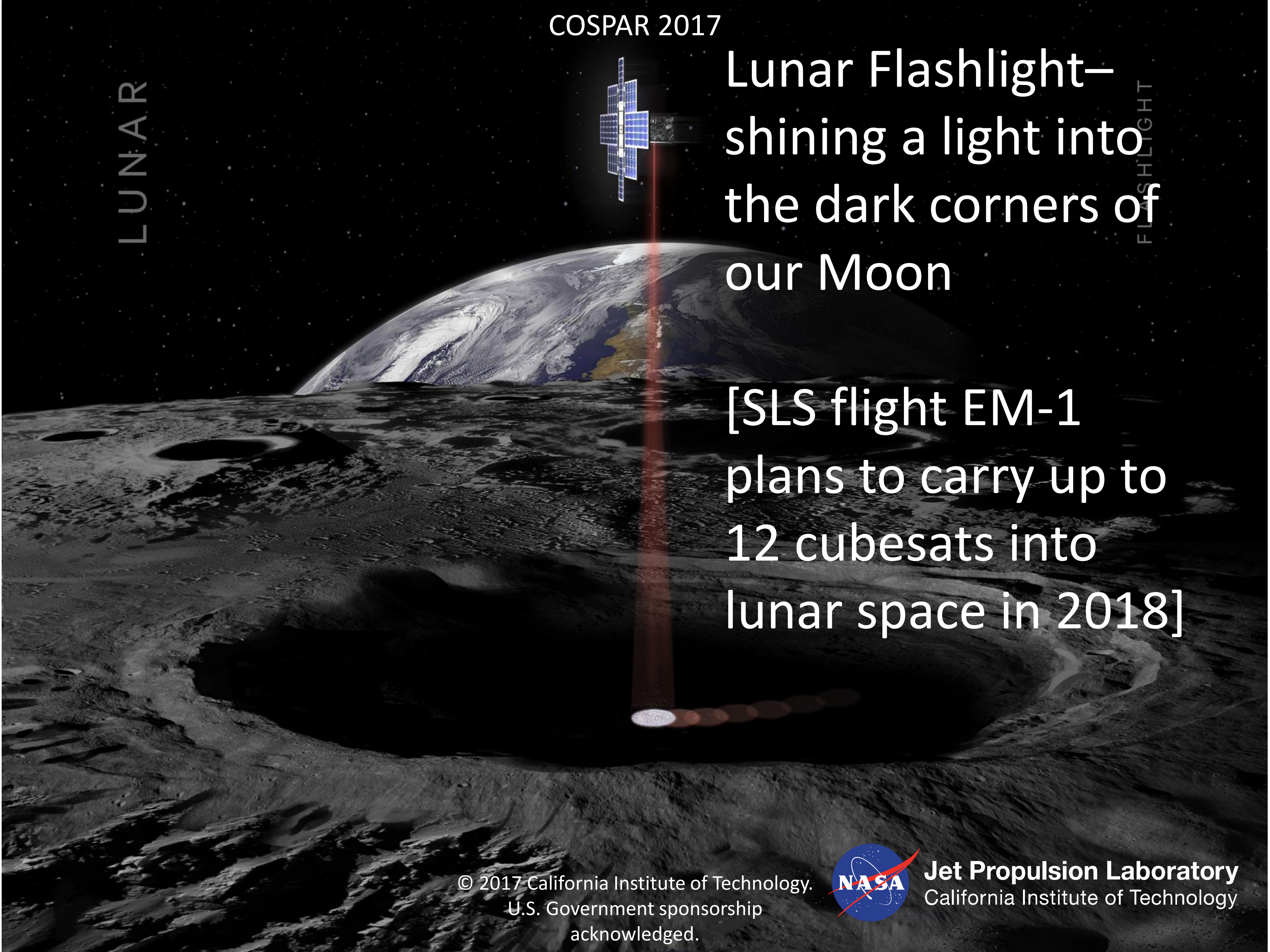
COSPAR 2017
LUNAR
Lunar Flashlight–
shining a light into
the dark corners of
our Moon
[SLS flight EM-1
plans to carry up to
12 cubesats into
lunar space in 2018]
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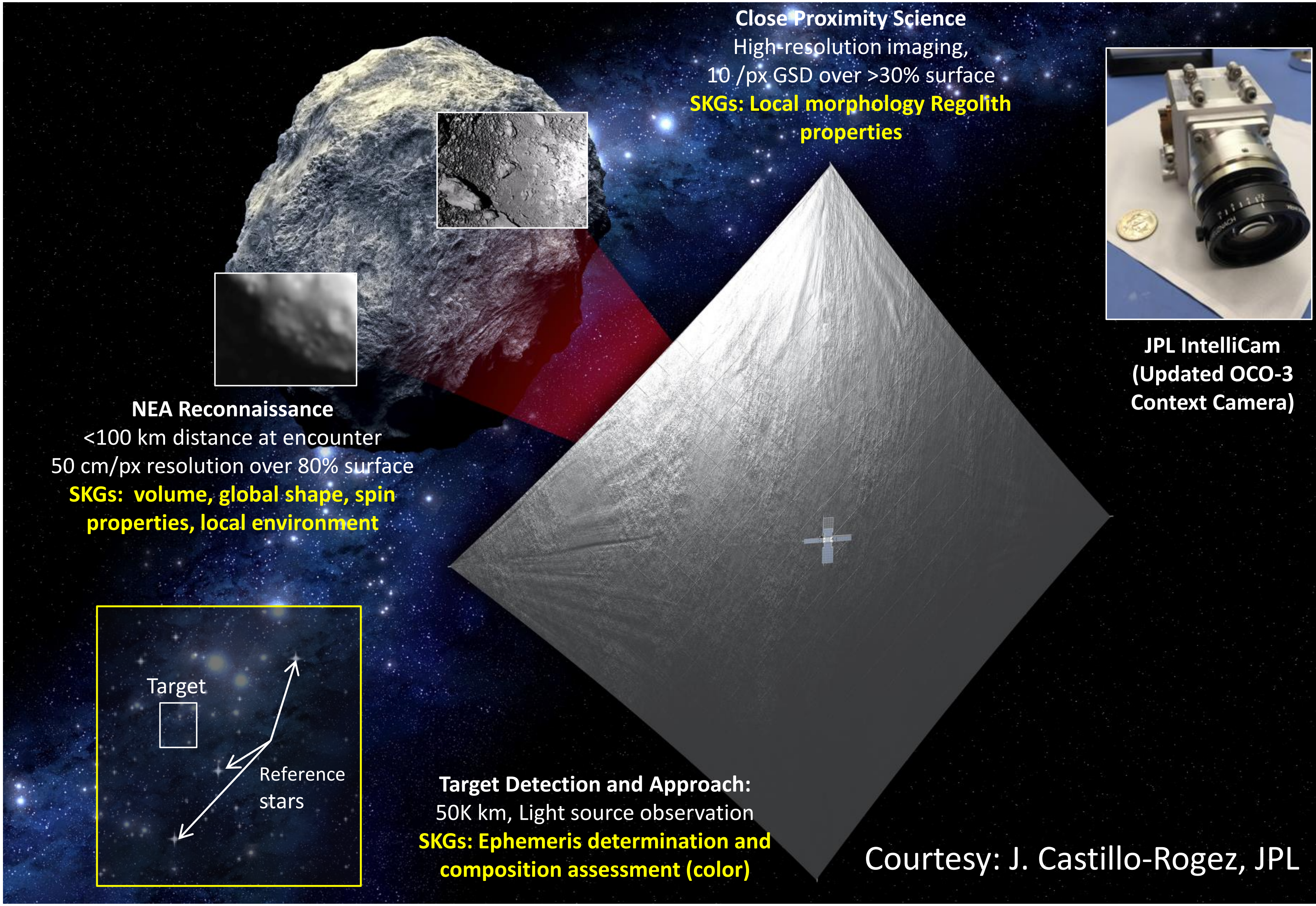
NASA
Jet Propulsion Laboratory
California Institute of Technology

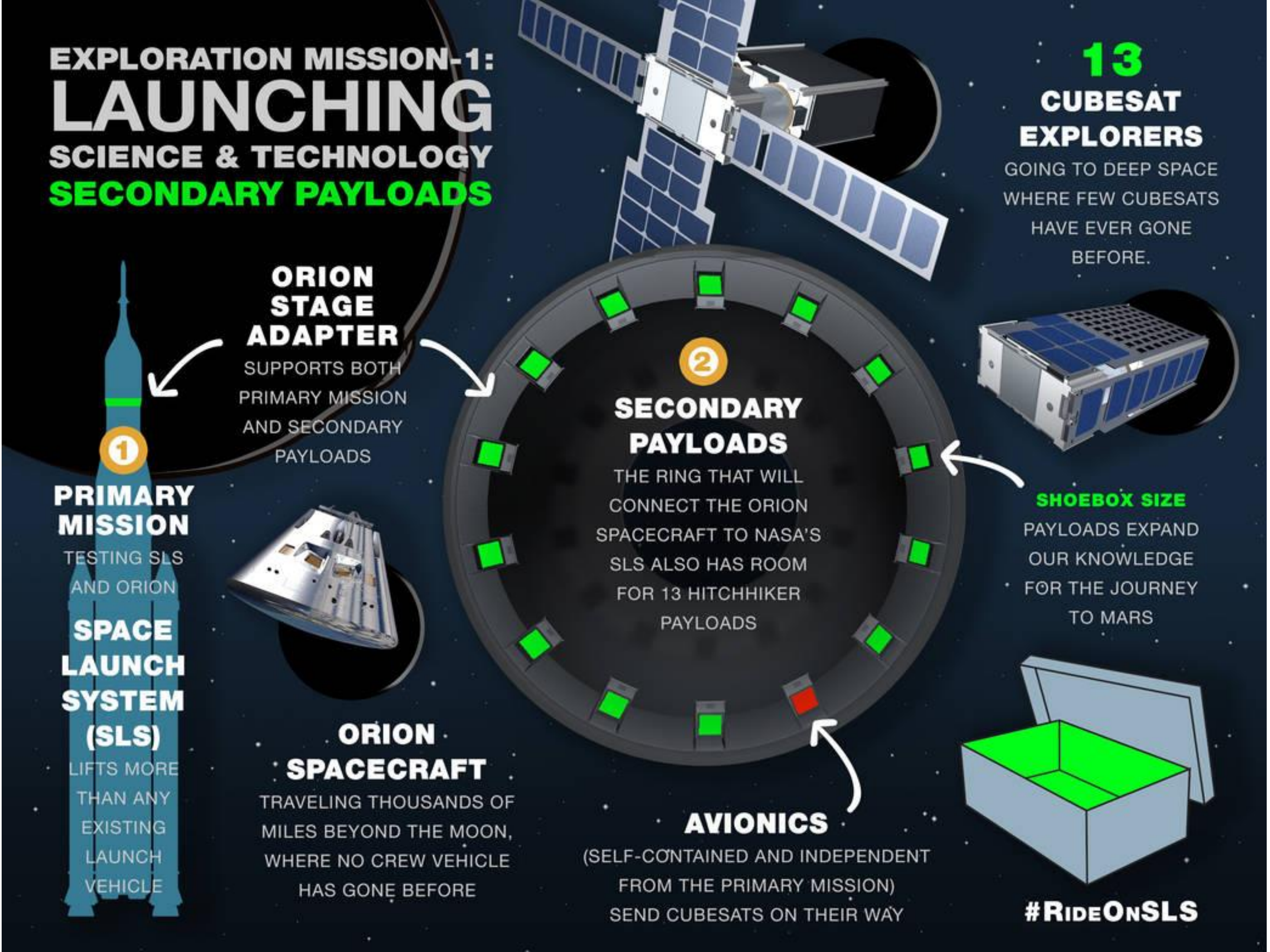
COSPAR 2017

NEAScout

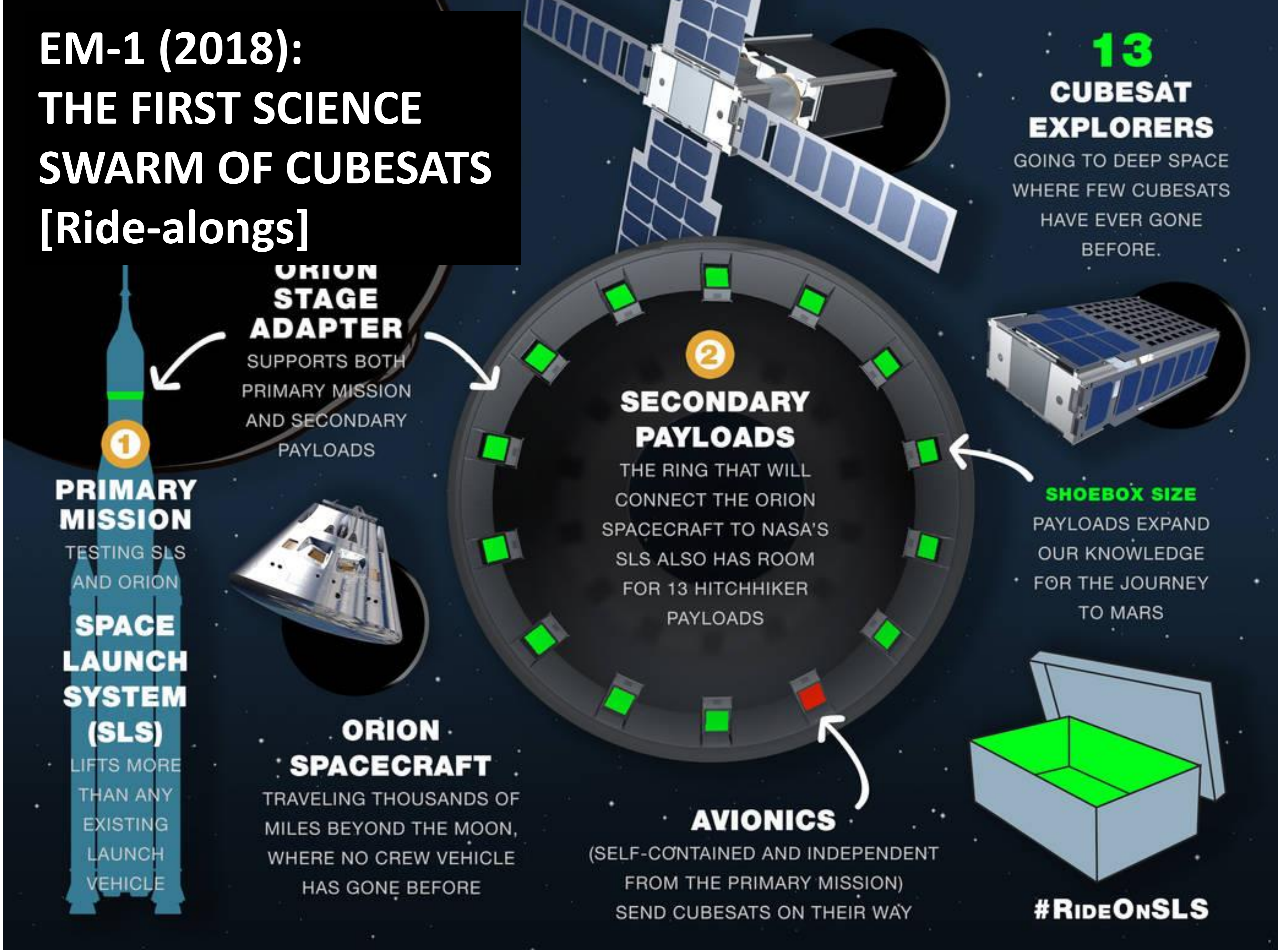
Near Earth Asteroid ScoutSat (NEAScout)

Jet Propulsion Laboratory
California Institute of Technology




EXPLORATION MISSION-1:
LAUNCHING
SCIENCE & TECHNOLOGY
SECONDARY PAYLOADS
ORION STAGE ADAPTER
SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS
1
PRIMARY MISSION
TESTING SLS AND ORION
SPACE LAUNCH SYSTEM (SLS)
LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE
ORION SPACECRAFT
TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE
2
SECONDARY PAYLOADS
THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS
AVIONICS
(SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION) SEND CUBESATS ON THEIR WAY
13
CUBESAT EXPLORERS
GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.
SHOEBOX SIZE
PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS
#RIDEONSLS

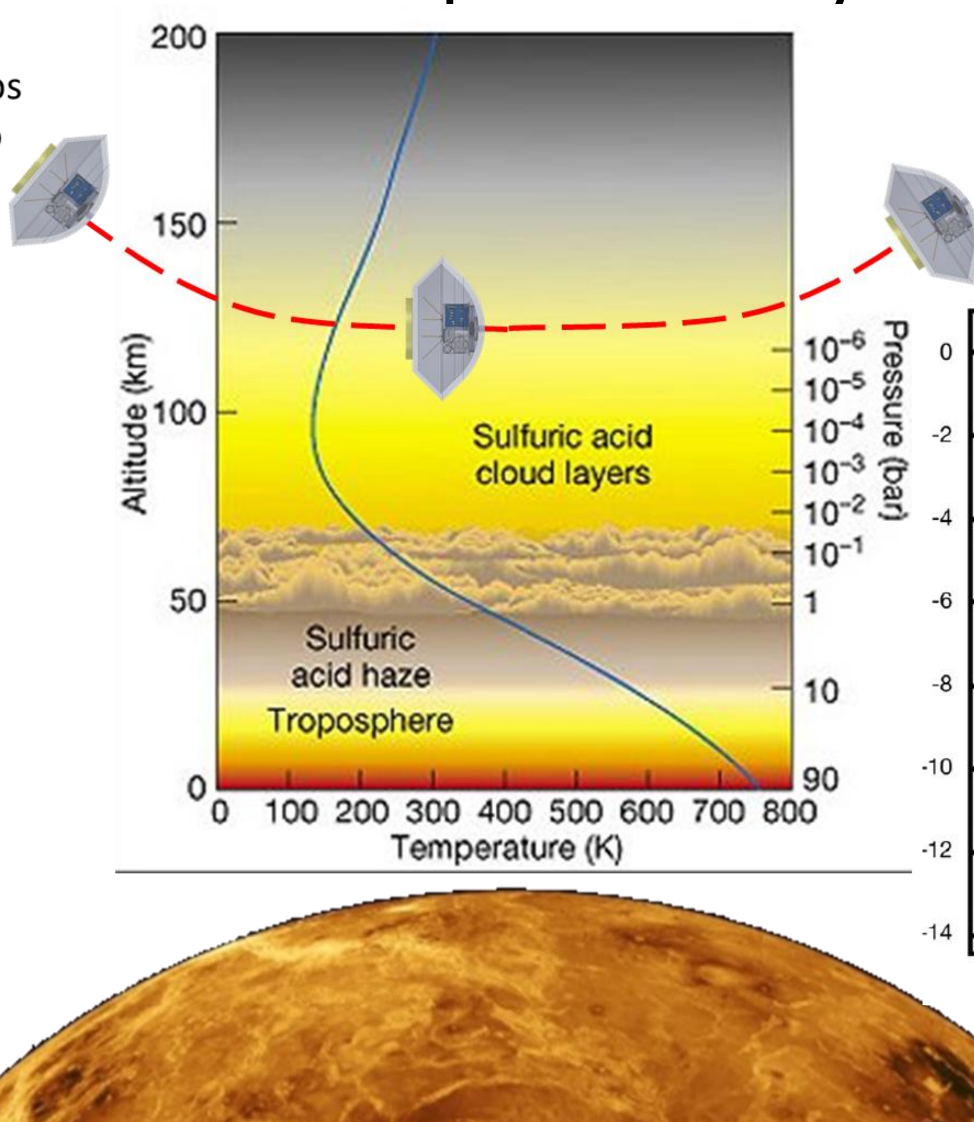
EM-1 (2018): THE FIRST SCIENCE SWARM OF CUBESATS [Ride-alongs]



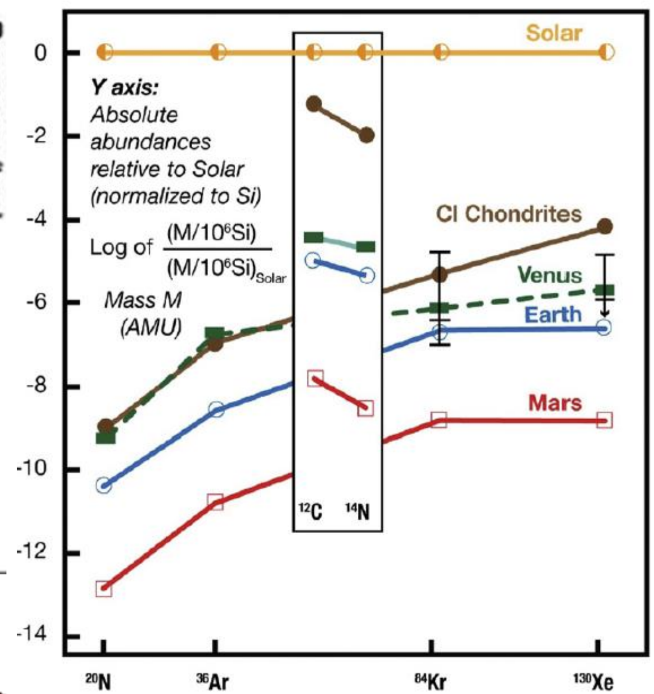
Cupid’s Arrow (Venus) Mission Concept

Atmospheric Entry Conditions

Probe dips down to 120km



- Recent DS^3 award of NASA funding to mature this mission concept
- PI: Christophe Sotin, JPL



Pepin et al., 1991; Chassefiere et al., 2012)

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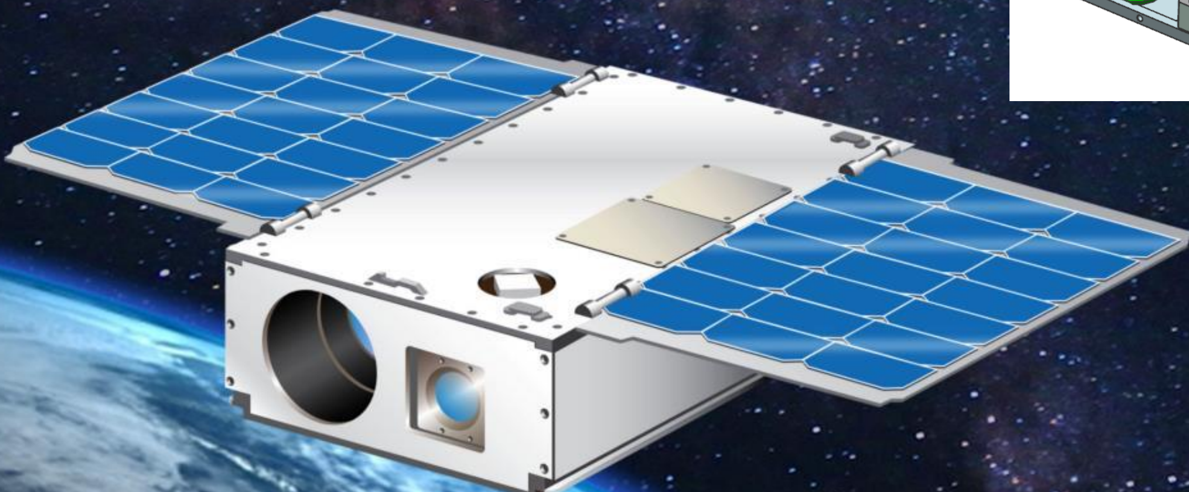
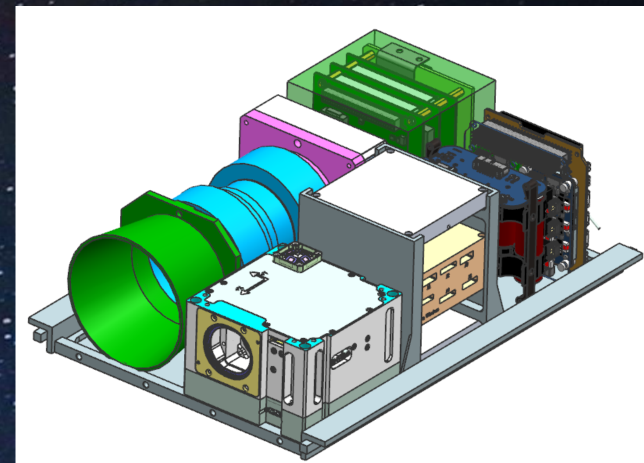
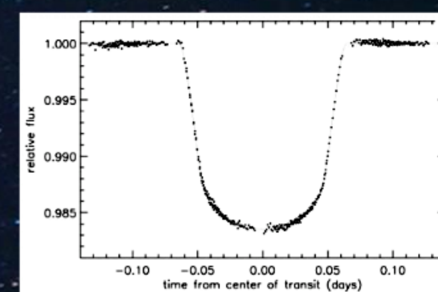
ASTERIA: Arcsecond Space Telescope Enabling Research in Astrophysics

- PI: Sara Seager, MIT
- Single star at-a-time planetary transits
- 0.1 arcsec precision pointing







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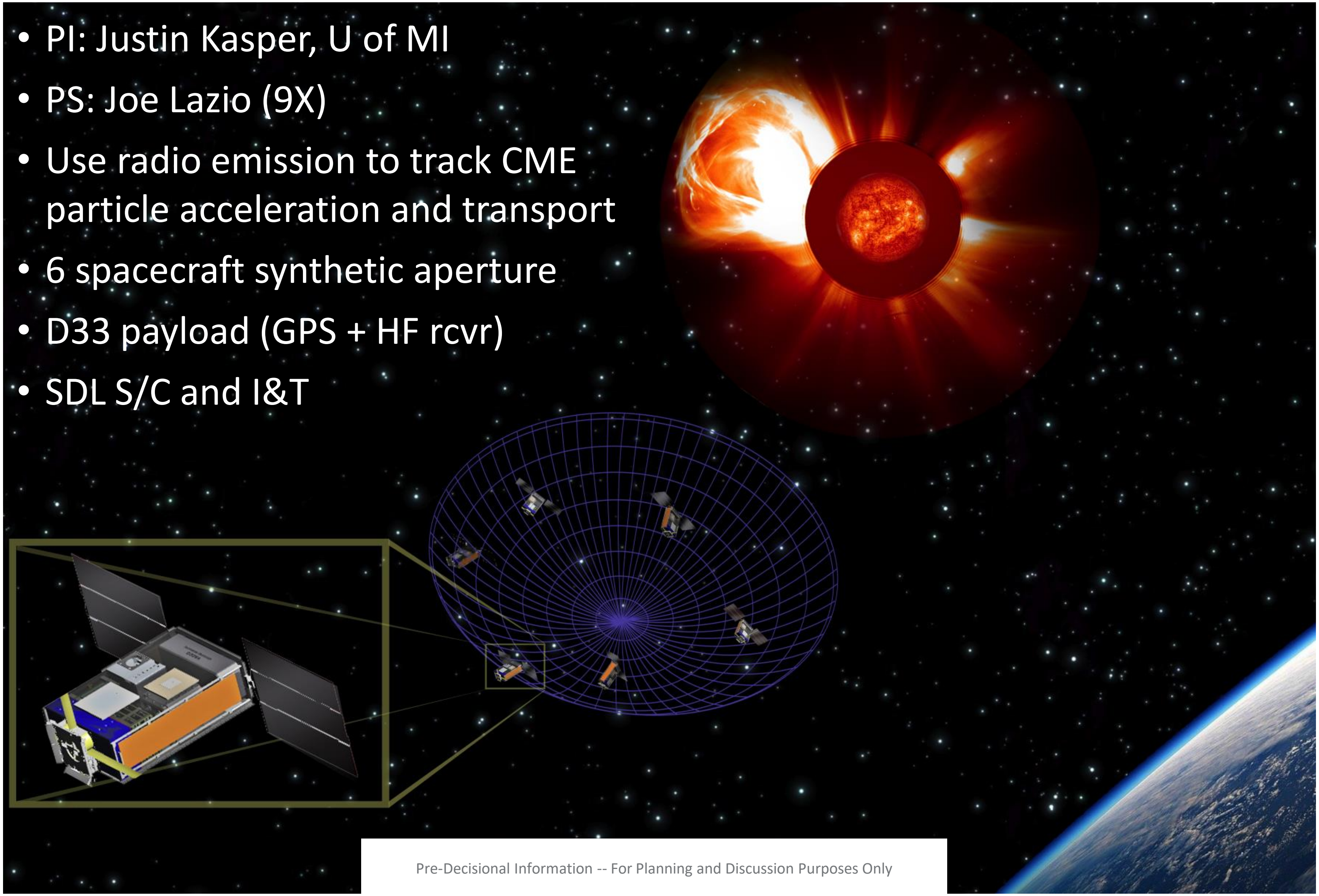
Sun Radio Imaging Space Experiment

SMEX Heliophysics Step II selection - Mission Concept

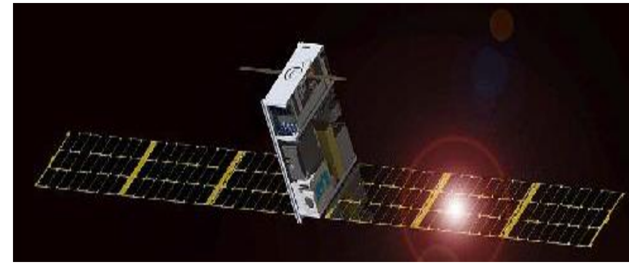
- PI: Justin Kasper, U of MI
- PS: Joe Lazio (9X)
- Use radio emission to track CME particle acceleration and transport
- 6 spacecraft synthetic aperture
- D33 payload (GPS + HF rcvr)
- SDL S/C and I&T



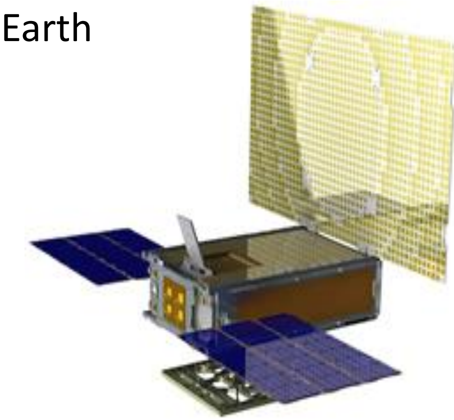
Pre-Decisional Information -- For Planning and Discussion Purposes Only

CubeSats at Saturn?

- Power
  - 1.2-2W solar power @ Saturn
    - **~ 11 days to fully charge 200 Whr capacity with 1.2 W array**
  - Up to 1200 Whr with primary batteries
- Control
  - <0.003° pointing; >35°/sec slew rates
- Communications (relay to primary)
  - X band with 5 W RF power
  - Antennas > 28 dBi gain X band
- Propulsion (chemical)
  - ~250 m/s ΔV for a 12 kg 6U
- Thermal
  - Some concepts would benefit from a compact RHU to survive thermal extremes



Lunar IceCube: 120 W @ Earth



MarCo 28 dBi

Slide courtesy Andrew Bocher, Cal Poly SLO

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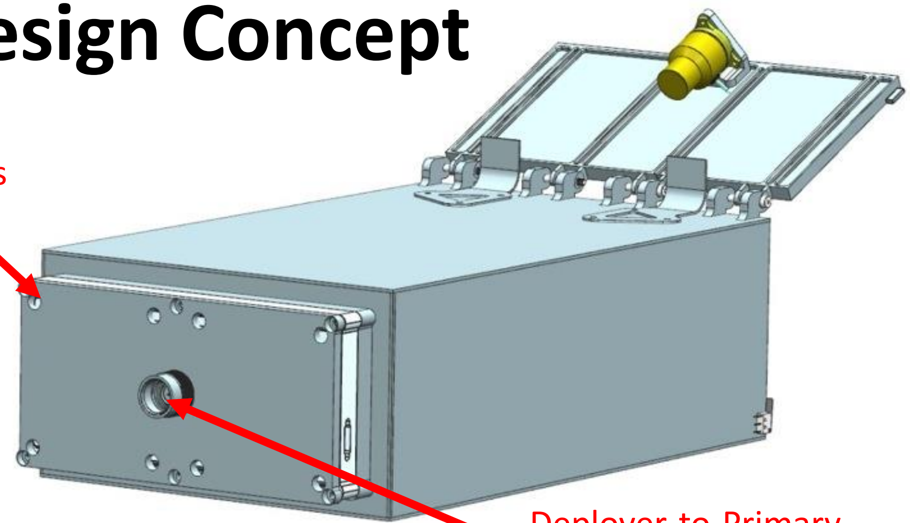
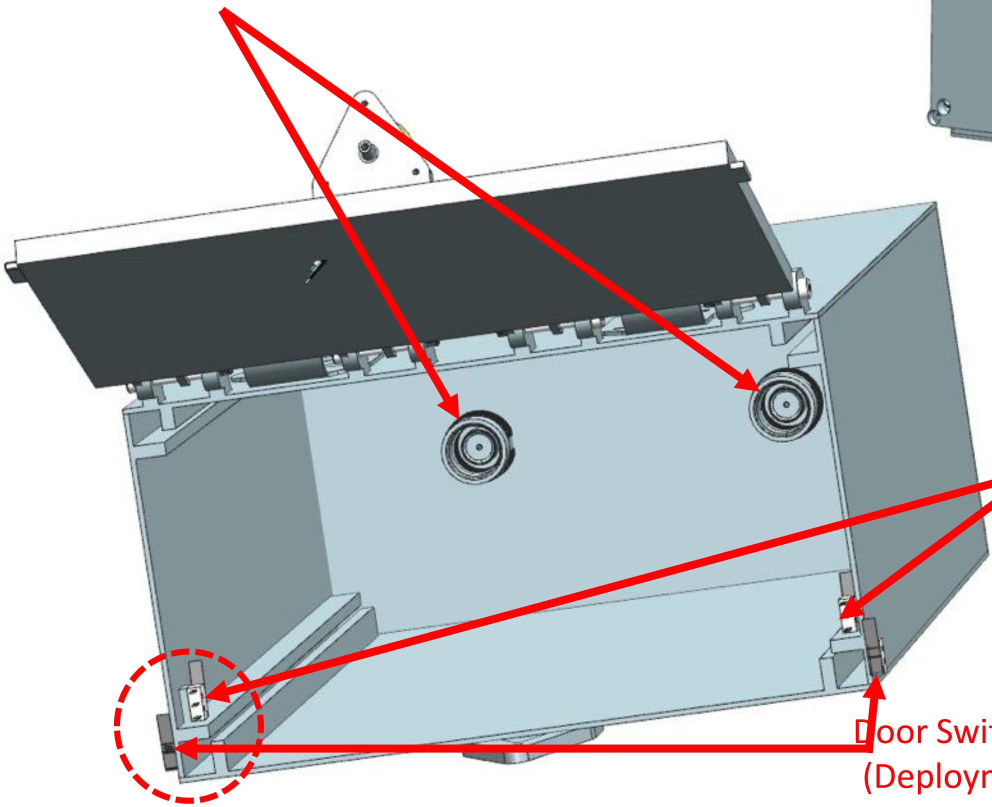
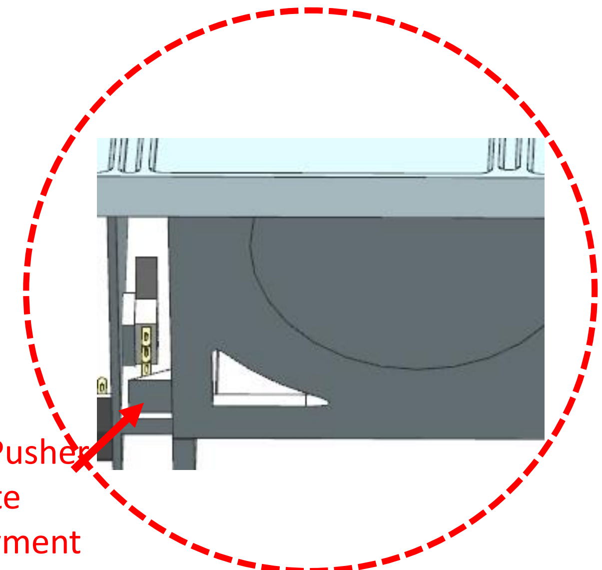
Deep Space Cubesat
Preliminary Deployer Design Concept

- JPL/Cal Poly joint study







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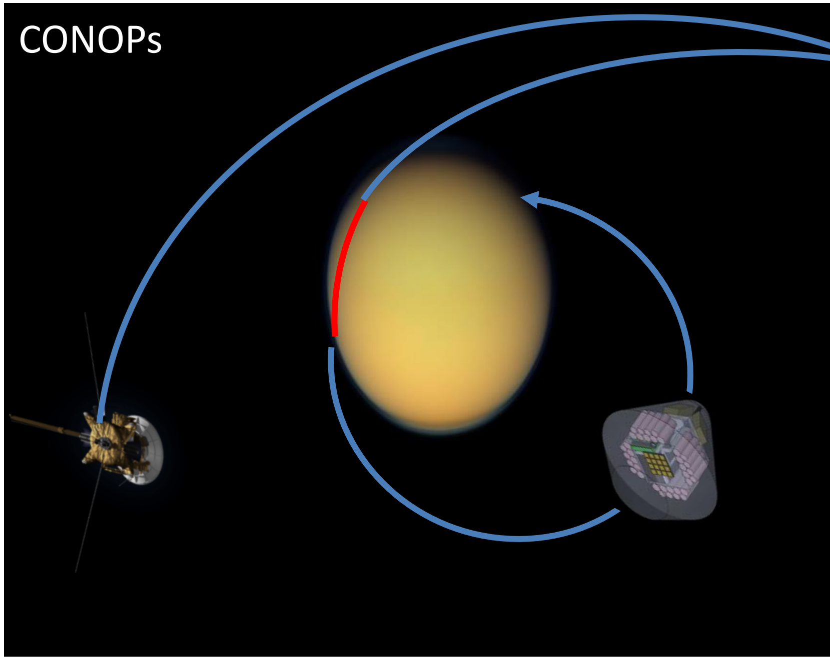
Titan Arrow Concept



Mission Overview

- Primary S/C orbiting Saturn with flybys of Titan
- **Probe released from Primary onto spin stabilized "dive" trajectory**
  - Primary deflects from entry trajectory post separation
- Probe skims through the atmosphere down to homopause (~500 km)
  - Collects in situ samples for mass spec analysis
  - Probe performs aerocapture maneuver
- Probe exits atmosphere, drops backshell and transmits data to Primary to be sent to Earth
- Probe disposed to acceptable location on Titan on next periapse pass

Science Overview

- Huygens Probe didn't sample upper atmosphere
- Upper atmosphere data desired for complete model

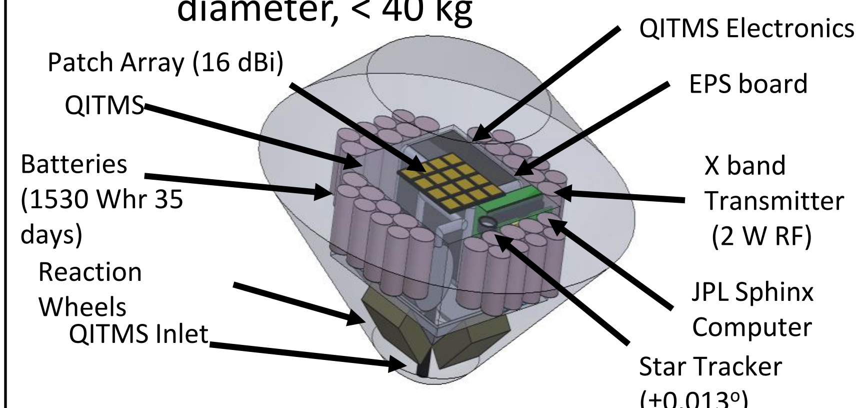
Titan Arrow Objectives:

- Determine Upper atmosphere constituents (Ne, Ar, Kr, Xe)

Constituents determined with Quadrupole Ion Trap Mass Spectrometer (QITMS)

Spacecraft Concept

- Galileo based 45^{o} sphere cone, ~0.55 m diameter, < 40 kg



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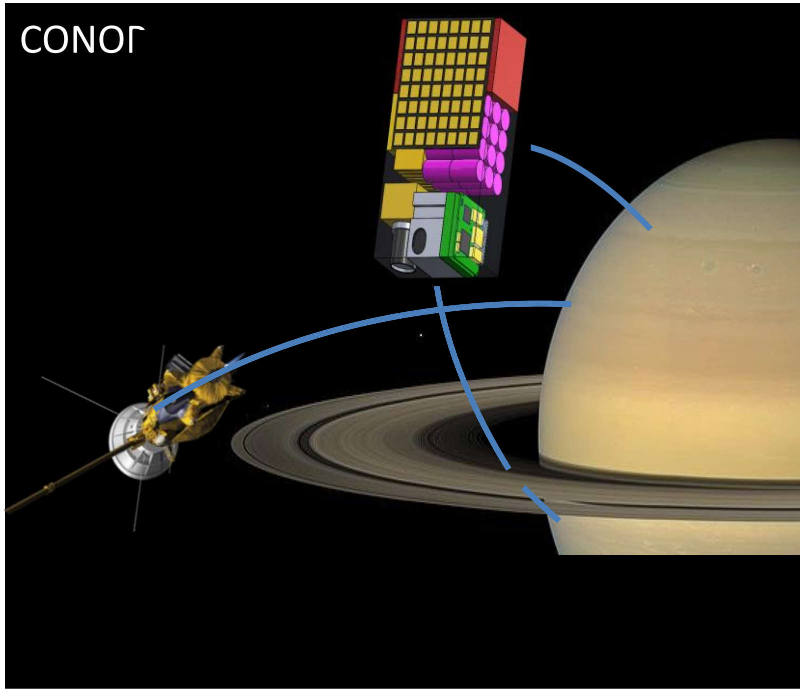
Saturn Ring Diver Concept



Mission Architecture

- 6U CubeSat rides along with primary mission to Saturn
- **Released at apoapse after Primary does Saturn orbit insertion**
- CubeSat performs inclination change maneuver ~45°
- CubeSat dives through narrow gap in rings while taking pictures
- If it survives, it transmits images to Primary via high gain antenna
- CubeSat continues in ring diving orbit if it survives, is destroyed by rings if it doesn't

Science Overview

Ring Science Gaps

- Mass, Age, Structure

Ring Diver investigates the ring structure by:

- Determine density of Saturn's ring (TBD)
- Size and distribution of ring particles
- Particle Morphology

Objectives achieved with <10 cm per pixel resolution camera

Spacecraft Concept

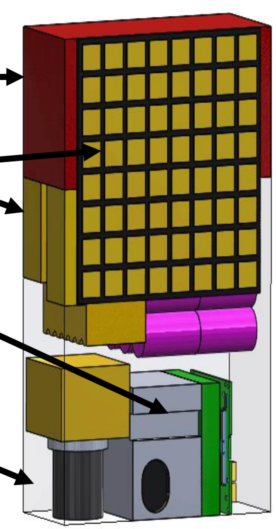
Aerojet Rocketdyne MPS120XW
(~250 m/s with AF-M315E)

IRIS Radio, 8x8 patch array
(100 kbps @150,000 km)

BCT XACT 50 (0.003° accuracy)

JPL Intellicam
(10cm/pixel at 800m)

Single RHU ~ 1 W heat



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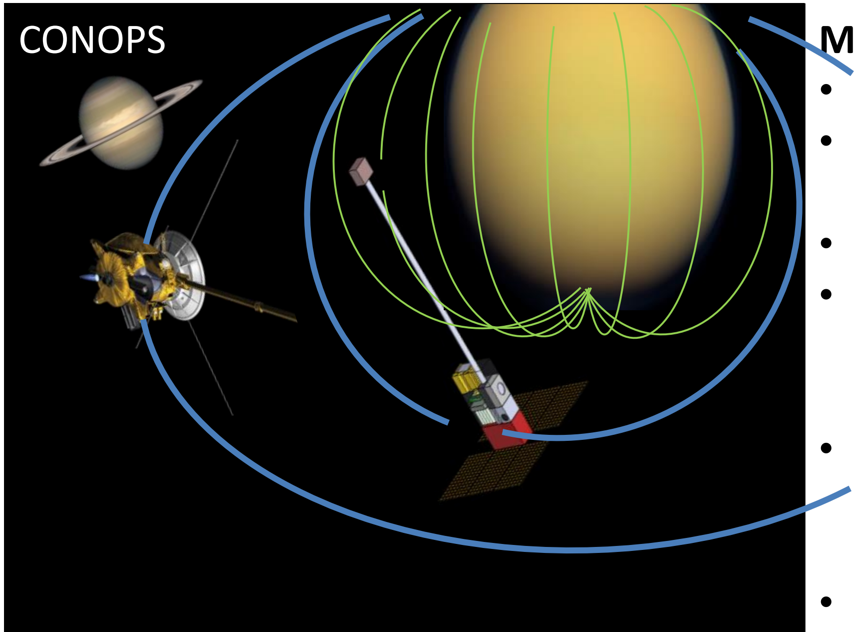
Investigating Titan's Magnetosphere



Mission Overview
- Primary Spacecraft inserts into Titan orbit
- **6U CubeSat released into same orbit**
  - ~5.8 hour orbit
- Deploys magnetometer on 0.6m boom
- 5 orbits of 1 and 0.03 Hz measurements for the magnetometer and plasma instrument respectively
- 90 orbits recharging batteries and relaying to Primary via S/C low gain antennas
  - Primary relays data back to Earth
- Disposal into Titan

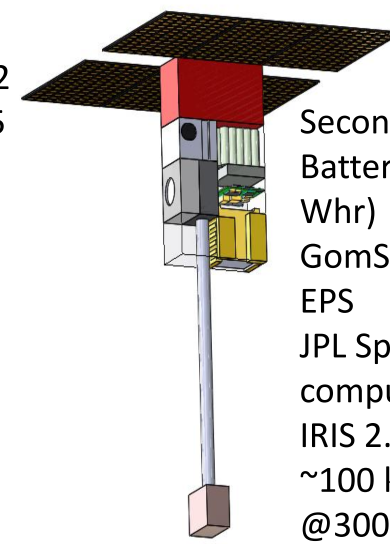
Science Overview
- Measure interaction of solar wind and Titan's magnetosphere
- Map Titan's magnetosphere

Objectives achieved with a Vector Helium magnetometer and Faraday Cup plasma instrument

Spacecraft Concept

6 panel solar array (1.2 W)
Aerojet Rocketdyne MPS12
~250 m/s with AF-M315
BCT XACT 50 (0.003°)
JPL PlasMag
(boom ~ 0.6m)

Single RHU (~1 W heat)



Secondary Batteries (~400 Whr)
GomSpace P60 EPS
JPL Sphinx computer
IRIS 2.1 radio
~100 kbps
@3000 km

Slide courtesy Andrew Bocher, Cal Poly SLO

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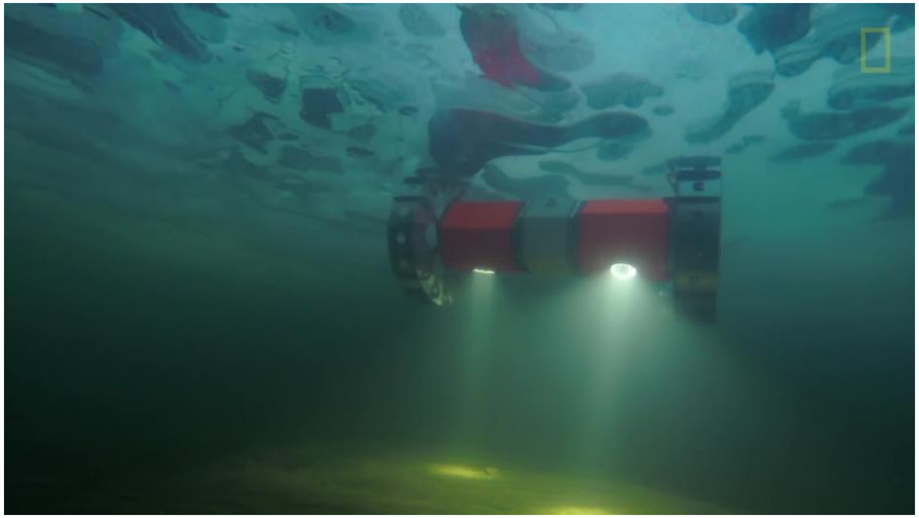
Predecisional information for planning and discussion only.

Concepts for Surface Mobility Systems

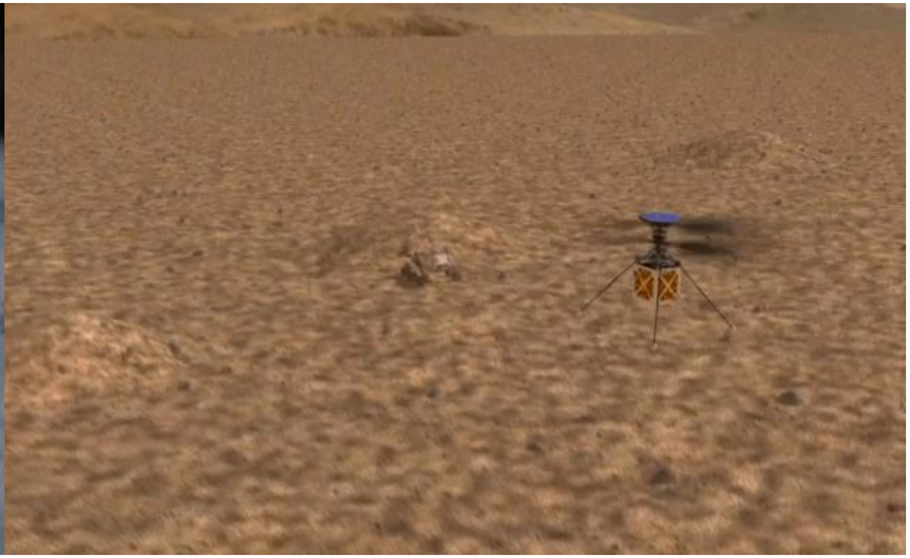
Under the Ice

- Subsurface probes
- Drones on Titan or Mars



Through the Ice

Exploring Mars



COSPAR 2017

Humanoid Robots

Kirobo on ISS

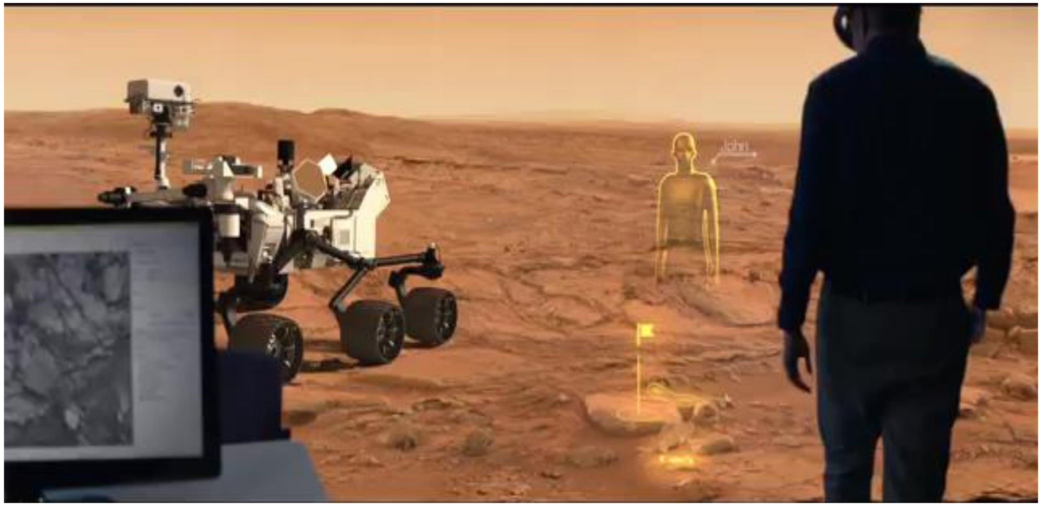
“That’s one small step for me”

Humanoid Robots

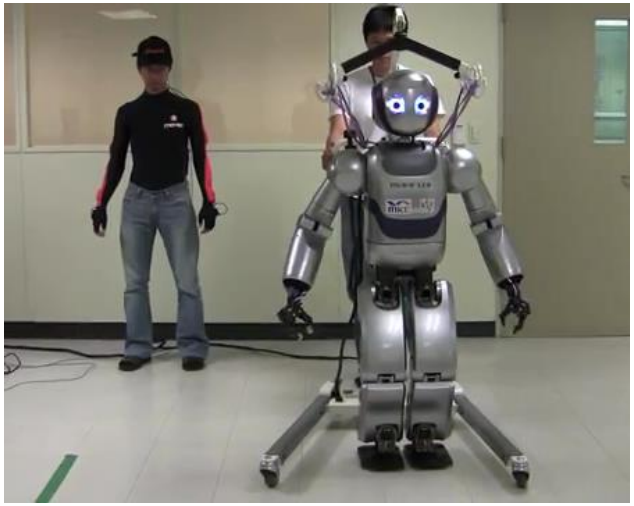
Artificial Intelligence?

Tool use - DARPA

Augmented Reality



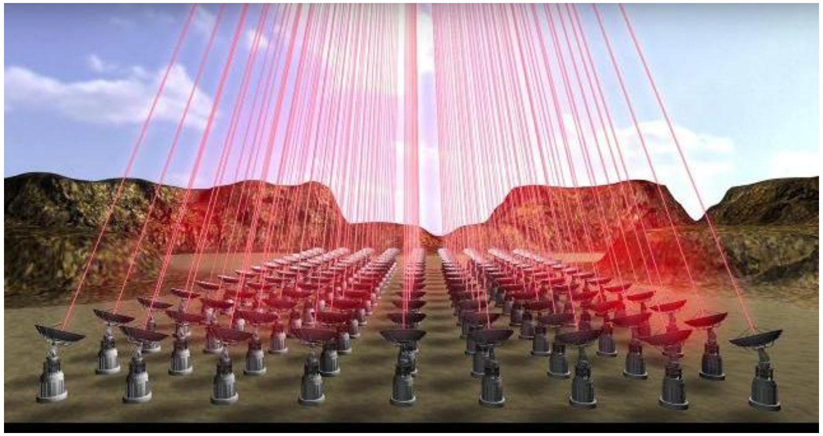
Motion Capture



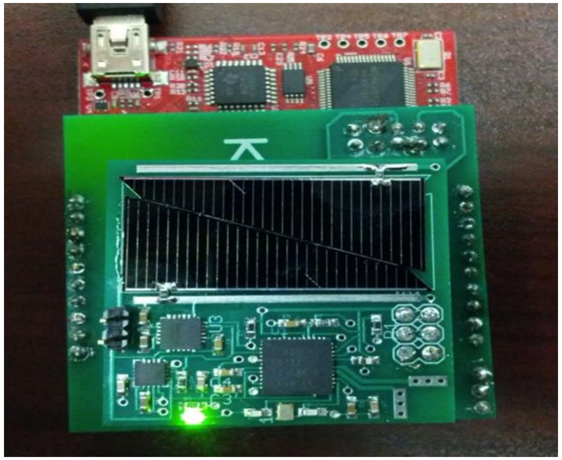
Going Interstellar

Breakthrough Starshot

breakthroughinitiatives.org/Initiative/3



Kicksat Sprite



picosat (1-2 g)

Summary

- The building blocks are lining up for some really exciting "Discovery-class" Smallsat missions in the very near future
- Miniaturization of instruments in particular has seen significant progress
- Smallsats allow fast-track infusion of technology for <u>all</u> future deep space missions
  - Don't have to wait 40 years like we did for solar sails
- On Earth, some technologies – smaller instruments, AI, robotics, adv. manufacturing – are taking off exponentially
- When these exponential technologies converge and are space-adapted they will open up mind-blowing possibilities!

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